NOTE ON MEASUREMENTS OF RADIO-ACTIV-ITY BY MEANS OF ALPHA RAYS.

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Art. XLV.—*Note on Measurements of Radio-activity by means of Alpha Rays;* by W. R. Barss.

It is a well known fact that in a gas ionized by α-particles a saturation current is obtained only when a much larger potential gradient is applied between the plates of the ionization chamber than is necessary when β- or X-rays are the ionizing agents. Bragg and Kleeman* showed that a current through a gas, ionized by α-particles, was still unsaturated when calculation showed that the number of ions lost by general recombination was small. The effect was ascribed to " Initial Recombination " ; i.e., to some of the ions being but partially separated from their parent molecules by the action of the α-particles. In the absence of an external electric field these ions fall back on their parent molecules and are thus neutralized. An intense electric field is supposed to complete the separation of the ions and to produce saturation. On this hypothesis, lack of saturation would not depend on the size or shape of the ionization vessel and saturation would be more easily obtained under diminished pressure.

Kleeman† has shown that lack of saturation with weak ionization by α-particles is not due to diffusion of the ions, nor does it depend on the recombination coefficient. He has shown that " Initial Recombination " is very small in gases ionized by β-, γ- and X-rays; in other words, these ionizing agents effect a more complete separation of negative ions from their parent molecules.

Moulin‡ has proposed an explanation of the mechanism of ionization by α-particles as follows. The ions formed by the α-particles are not distributed uniformly throughout the gas, but each α-particle has, associated with it, a column of ions, the axis of the column being along the path of the particle. Lack of saturation is explained by recombination of ions of opposite sign within each column. This recombination between ions of the same column ought to exceed that which would be obtained for the same number of ions distributed throughout the volume of the gas. The amount of the recombination between ions of the same column should be much greater when the field is applied in a direction parallel to the direction of the column, than when it is applied in a direction perpendicular to it; for the parallel field would leave the columns intact, while the perpendicular field would break each column into two parts by

* Phil. Mag., xi, p. 466, 1906.
† Phil. Mag., xii, p. 273, 1906.
‡ Le Radium, May, 1908, p. 136.

separating the positive and negative ions. Hence the lack of saturation should be more apparent in the former case than in the latter. These facts were experimentally determined by Moulin. He obtained saturation for the parallel field at 1200 to 1500 volts per centimeter while for the perpendicular field only about 200 volts per centimeter were necessary.

Moulin concludes that general recombination within the columns (proportional to the square of the density of ionization within the columns) is so much greater than "Initial Recombination" that the latter is negligible in comparison.

Ionization by a-particles was further investigated by Wheelock;* among other results, he obtained the following. When an electric field is applied parallel to the path of the a-particle and therefore parallel to the axis of the column of ions, the column would not be broken up and the recombination occurring would be between ions belonging to the same column. Since each particle makes the same number of ions along its path, the density of ionization would be the same in any one column and therefore it would be expected that the ratio of currents obtained with sources of different intensities would be constant for different potential gradients applied. When the field is applied perpendicular to the column and when the source of ionization is small, very few columns would exist in the ionization vessel during the time required for the ions to be carried over to their respective electrodes. Hence there would be little chance for recombination between the columns, so that it would be expected that the ratio of currents obtained with sources of different intensities would be constant as in the case of the parallel field. When the field is perpendicular and the source of ionization is stronger, enough columns might exist between the electrodes at one time to make recombination possible, not only between ions of the same column but between those of different columns. In this case the ratio of currents obtained with different source intensities might not be constant because of the added recombination of ions of different columns.

Wheelock found that the ratio of the current produced by a more intense source of rays to that produced by a weaker source is constant for the parallel field; that it is approximately so for the perpendicular field when the sources are both weak, and that it increases slightly with the potential gradient applied when the sources are stronger. This is as would be expected if the ions formed by a-particles are arranged in columns.

When the gas is ionized by β- or X-rays it would not be expected that the ratio of currents obtained for different source

* This Journal, xxx, 233, 1910.

intensities would be constant. Here the ions are distributed throughout the volume of the gas, and general recombination, which depends upon the ionization density, i.e., upon the number of ions per cubic centimeter in the gas, would increase as the ionization itself is increased, unless a saturating field is applied.

In a great number of important investigations in the subject of radio-activity, it has been assumed that the quantity of radio-active material present was proportional to the ionization currents produced by the a-rays. In these experiments, electrical fields have been applied which would have been ample to cause saturation if the ionization had been produced by β- or X-rays, but which are now known to be quite inadequate to produce saturation when a-rays are employed. Results which have been obtained in this way are of fundamental importance in the theory of radio-active transformation. They include the determination of relative quantities of radio-active substances by the "Emanation Method" and the method of thin films, as well as nearly all the measurements of rates of decay of such substances. It is safe to say that in no case in which such measurements have been made with an electroscope, in air at atmospheric pressure, has a saturating potential been applied, or even very closely approached. The fact that a fairly consistent body of measurements and constants has been built up by many investigators, notwithstanding this apparent flaw in their experimental arrangements, shows that the considerations advanced above must have a considerable degree of validity. The object of the present experiments is to test this point specifically in the important case when the a-rays are produced by an emanation mixed with the ionized gas. In this case the sources of the rays are scattered through the gas and on the walls of the vessel, and the paths of the a-particles and their attending columns of ions extend in all directions ; so that the geometrical complication is as great as it can well be.

We might reasonably expect the ratio of currents to be constant in this case, at least for small source intensities. If the number of a-particles is small, there will be only a few columns of ions existing together during the time required for the ions to be carried to their respective electrodes. It is true that a portion of the a-particles will cross each other and that the separated columns of ions will also sometimes cross each other, thus producing some recombination between ions of different columns. But even when this happens, the crossing will usually be at an angle, and the length of each column is so great compared with the diameter of its cross section that even if they do intersect, the amount of this recombination will be neg-

ligible compared to the recombination between ions of the same column.

As the intensity of the source is increased, the number of columns of ions existing together is also increased. The probability that different columns will cross each other is greater and therefore the amount of recombination between ions of different columns will be greater. So that, as in the case of the perpendicular field, the ratio of the larger current to the smaller will probably increase as the potential gradient is increased.

In the present experiments, a cylindrical tin chamber was used $13 \cdot 5^{cm}$ high and $10 \cdot 5^{cm}$ in diameter. A central brass

Fig. 1.
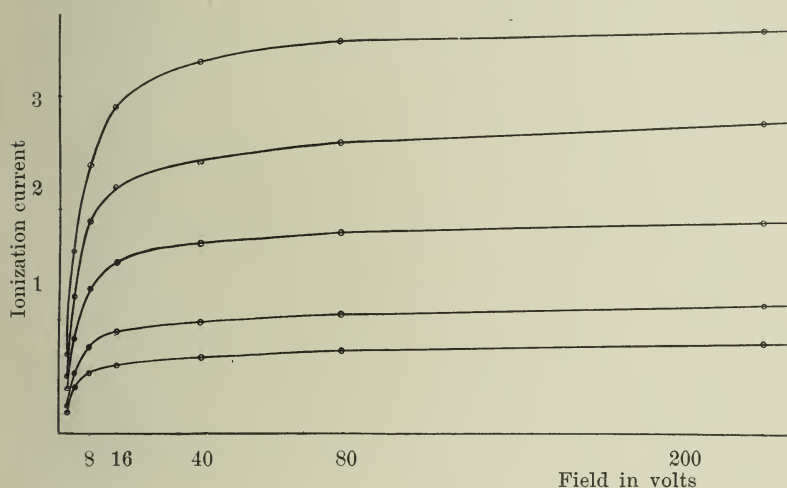
electrode, provided with an earthed guard ring, was connected to a tilted electroscope of the Wilson type, the leaf of which was observed by means of a microscope having a graduated scale in the eyepiece. This central electrode and the leaf of the electroscope were grounded through a potentiometer by means of which each deflection due to the ionization current was calibrated in terms of potential. The capacity of the system was kept constant, so that these calibrated readings varied directly as the actual ionization currents. Different potentials were applied to the case of the chamber. Radium emanation was used as an ionizing agent; it has a half value period of about four days, so that it provided a suitable source of varying intensity.

One series of observed data is given in the following table V is the potential in volts applied to the case. C_1 represents the corresponding ionization current for a given intensity; C_2 the ionization current for a weaker intensity, etc.

V	C_1	C_2	C_3	C_4	C_5
2	·72	·55	·40	·23	·16
4	1·60	1·15	·85	·50	·38
8	2·50	1·90	1·40	·80	·55
16	2·90	2·20	1·50	·96	·65
40	3·35	2·40	1·75	1·05	·75
80	3·53	2·58	1·86	1·10	·78
200	3·65	2·80	1·95	1·16	·80
400	3·80	2·90	2·05		·83
600	3·90	3·00	2·08		

A series of curves plotted from these data is given in fig. 1: abscissæ represent the potential V applied to the case. Curve 1 has for its ordinates the values given in C_1 above, curve 2 the values in C_2, etc.

Ratios of ionization currents are given in the following table:

V	C_1/C_2	C_1/C_3	C_1/C_4	C_1/C_5
2	1·31	1·80	3·13	4·50
4	1·39	1·88	3·20	4·21
8	1·31	1·80	3·12	4·54
16	1·32	1·93	3·02	4·45
40	1·39	1·91	3·19	4·46
80	1·36	1·89	3·21	4·52
200	1·30	1·87	3·14	4·56
400	1·31	1·85		4·57
600	1·30	1·87		

It is evident that the current ratios are constant within the limits of experimental error.

In the above data the potential applied to the case was negative. A series of readings was made with the potential positive giving similar results.

The radium emanation used was drawn from carnotite, the amount of emanation being equivalent to the amount in equilibrium with about 10^{-6} gm. of radium. It remains to be tried to what degree the intensity may be increased before there is a change in the current ratios.

Summary.

When the a-particles are moving in all directions with respect to the electric field, and when the source of ionization is not too intense, the ratio of the currents obtained from two sources of different intensities is constant for different potentials applied to the ionization chamber.

No great errors are involved even when currents are used less than one-fifth of the saturation value.

In conclusion, I want to thank Professor Bumstead for his many suggestions throughout the experiment.

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